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Review Article

Effects of Cadmium Toxicity in Plants: A Review Article

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Abstract: Heavy metals, for example, cadmium, copper, lead, chromium and mercury are considered as major environmental pollutants. Among all heavy metals, cadmium (Cd) is a non-essential metal which has pulled in the consideration of specialists in soil science and plant nutrition because of its potential harmfulness and toxicity to living beings, furthermore because of its relative mobility in the soil plant system. This survey underlines the dangerous side effects or toxic symptoms of Cd in plants i.e. growth retardation, alternations of photosynthetic activity, change in stomatal movement, enzymatic activities, protein metabolism, membrane functioning furthermore outlines the mechanisms of cadmium uptake, translocation , deposition and cadmium-induced oxidative stress . This survey/review may likewise help in interdisciplinary study to evaluate/access ecological significance of the metal toxicity and stress.
Keywords: Cadmium, toxicity, photosynthesis, stress.

INTRODUCTION

Heavy metals are characterized as the metals that have a density greater than 5 g cm^3. Among 90 naturally occurring elements, 53 are designated as heavy metals and some are biologically important [1]. On the basis of their solubility under physiological conditions, 17 heavy metals can be considered for being accessible to the living cells and have significant role in plant and animal communities within various ecosystems [2]. They are considered as significant environmental pollutants that [3,4,5]. As per [6], non-contaminated soil contain Cd concentration ranging from 0.04 to 0.32 mM. Soil that have a Cd concentration ranging from 0.32 to around 1 mM are considered as contaminated to a moderate level. As Cd is naturally present in all soils, so all the food stuffs will contain some amount of Cd and subsequently all living beings including humans are exposed to natural levels of Cd. It has been accounted earlier that leafy vegetables and potato tubers accumulate more elevated amounts of Cd when contrasted with fruits and cereals. In addition, tillage and crop rotation practices have a more noteworthy effect upon the Cd content of food in comparison to that of Cd concentrations in soil [7]. Cadmium accumulation in the environment is presently turning into an essential reason for environmental pollution. Cadmium (Cd) is a standout amongst the most deleterious trace heavy metals both to plants and animals. Industrialization and culture cause Cd the most harmful and widespread pollutants in agricultural soils, and soil-plant-environment system [8]. The maximum tolerable intake limit of Cd for human beings, suggested by FAO/WHO is 70 µg/day [9]. Cd contamination is of expanding investigative interest since Cd^{2+} is taken up readily by the roots of all most all plant species and its harmfulness/toxicity is thought to be 2–20 times higher than other heavy metals [10]. Cd phytotoxicity is a minor, yet an important issue, particularly in exceedingly heavy metal contaminated locales/regions, where a diminishing in agricultural crop productivity has been noticed. The main aim of this review is to focus our present understanding on the factors that utmost the development of plants exposed to Cd treatment.

Mechanism of cadmium uptake, translocation

Plants respond to expanded levels of Cd in soil differentially, regarding the capacity of different plants species uptake and transport Cd. Cd is effectively transported inside plants [11] as metallo-organic complexes. The bio-accessibility of Cd in soil relies on its pH, concentration, redox potential, temperature, and concentration of different elements. Rhizosphere acidification and carboxylase exudation are considered as potential targets for upgrading accumulation of metals[12]. Mechanisms involved in the uptake of Cd by the root of plants generally includes competition for absorption sites between the heavy metals and a few mineral nutrients having comparable/similar chemical properties [13]. The decrease of metals like K, Ca and Mg in tissue because of high level of Cd has been seen in tomato and cucumber plants [14], maize [15] and lettuce. An antagonistic relation amongst cadmium and zinc and their active absorption has been seen in roots of lettuce [16]. Other mineral nutrients, for example, nitrate, which does not have similar chemical properties with Cd, are also influenced by its presence. Cd first enters into the roots and harms the root system first [17]. The mechanism controlling the Cd uptake by roots of plants and amassing in consumable/edible parts are yet not fully understood. The electrochemical potential difference between the action of Cd^{2+} in the cytosol and in the root apoplasts controls the absorption of Cd across the plasma membrane of root cells. Enough energy is given by the large membrane potential to drive Cd^{2+} uptake even at low levels/doses of Cd^{2+} .The energy of Cd^{2+} absorption by roots demonstrates bio-phasic qualities with saturable components at low Cd^{2+} activities in the absorption solution and a linear components at higher Cd activities [18]. Absorption of Cd can likewise happen as inorganic complexes (for example, $CdCl^+$, $CdCl_2$ and $CdSO_4$) [19] or else as organic complexes, for example, phytometallophore complexes. [20] noticed that Zn(II) phytometallophore complexes were promptly taken up by maize roots however the binding sites in the root plasma membrane are not exceptionally particular for Fe(III) phytometallophores, along these lines likewise permitting the transport of different metals like Cd. In any case, there is no immediate confirmation for Cd binding with phytometallophores during its transport ation in the root cells. Different metals, particularly Zn^{2+} collaborate with Cd and lessen uptake during Zn-insufficient/deficient conditions and it is clear from the evidence that cereal roots developed under Zn-insufficient /deficient conditions are implicated in diminished Cd uptake following the application of Zn [21]. Cadmium effectively penetrates the root system of xylem through both apoplastic and/or symplastic pathway [22] and therefore reaches tissues of plants specifically aerial [23]. The metal content is greater or more prominent in the root than in the above ground tissues of plants regardless of the distinction of metal ions mobility [24]. Generally Cd particles are held in the roots and just little amounts are transported to the above ground parts [25]. The concentration of Cd in plants diminishes in the order: root > leaves > fruits > seeds/grains [26, 27]. The degree of Cd transport into edible organs varies generally among crops. In soybean more than 98% of the Cd accumulated was held by roots and just 2% was transported to shoots/above ground parts [25]. Additionally, Cd was effectively transported to the shoots and leaves yet was not detected in fruits of tomato plants [28]. After uptake by the roots Cd is transported to the shoots, through the cells of vascular bundles. Transport of the trace metal is likewise directed by vascular tissues [29]. There are various cell membrane obstructions that Cd must cross to enter consumable/edible plant organs and this is particularly true for seeds and grains.

Cadmium Deposition

The aggravates that bind Cd in mature seeds amid their development are not known. Cadmium may bind to phytate (myo-inositol hexaphosphate) in globoid crystals inside the protein structure of developing seeds. Different metals (Fe, Zn, Mn, Mg and Ca) have been accounted for to be associated with phytate inside globoid crystals of these organelles. [30,31, 32] reported that phytate globular deposits containing Zn was formed in small vacuoles of root cells inside the elongation zone of roots of soybean, maize and wheat. Furthermore, Cd was not bound to phytic acid in these little root-cell vacuoles. Alternatively, Cd could be found to second class metallothioneins in developing seeds and grains since genes for the expression of these sulphydryl-rich proteins have been accounted for in seeds of some plant species like wheat and maize [33,34]. Further research directed to determine the major type of Cd in edible parts of crops demonstrated that in oat (*Avena sativa* L.) roots, Cd transport from cytosol to the vacuole over the tonoplast is exhibited through Cd^{2+}/H^+ antiport movement and stored in cell compartments [35].

Effect of Cd on stress proteins

Changes in the environment can bring about change in gene expression, in this manner prompting change in the diversity of proteins in the cell. Therefore, changes in level of protein under stress conditions can be molecular markers for the manifestations of the responses to stress in living beings. In plants, the proteomics methodology is developed as a critical strategy for research on stress resistance/tolerance [92]. Heat-shock proteins (HSPs) are known as proteins that have functions to tolerate stress in eukaryotes.

Table 1: Toxic symptoms induced by Cadmium

Parameters	Effects	References
Photosynthesis	Retards photosynthesis	[36,37,38]
	Hindered stomatal opening in *Syzygium aromaticum*, *Medicago sativa* , *Glucine max*	[39,40]
	Chlorotic leaves, changed ratios of chlorophyll a and b, decreasing net photosynthetic rate	[41,42,43,35,44]
	Destructs the photosynthetic apparatus particularly the light harvesting complex II	[45]
	Destructs photosystems I and II	[46,47]
	Inhibition of root Fe(III) reductase	[48]
	Overall destruction of photosynthetic efficiency	[49,50,37]
	Diminished chlorophyll and carotenoids content, and increased non-photochemical quenching in *Brassica napus*	[51,52,53,54,55, 56,57,58,59]
Fresh weight and dry mass	Diminished the fresh mass in *Vigna radiata*	[60]
	Decline in root and shoot mass in *Vigna ambacensis*	[61]
	Decrease in dry mass in *Cicer arietinum*	[62,63]
Protein	Inhibition of protein synthesis	[64,65,66,67]
Carbonic anhydrase	Retards the activity of carbonic anhydrase	[68]
Proline	Increase in proline in *Oryza sativa* , *Brassica napus*, *Armeria moritima*, *Helianthus annus*, *Brassica juncea*	[69,70,71,72,73, 74]
Lipid peroxidation	Membrane leakage, change of lipid composition	[75,76,77]
Cellular concentrations	Changes in cellular concentrations of essential micronutrients like iron, calcium, manganese, zinc	[78,79,80,]
Root ultrastructure	Inhibition of root elongation, increase in volume of cortex cells, damage to epidermis	[81,82,41,83]

Table 2: Cadmium-induced signaling events mediated by reactive oxygen species (ROS) in different plant species

Plant species (References)	Cd concentration	Time of treatment	Signaling events
Oryza sativa [84]	100µM $Cd(NO_3)_2$	13 days	Accumulation of H_2O_2 and modification of the auxin signaling pathway and/or cell-cycle gene expression
Oryza sativa [85]	5mM $CdCl_2$	24 h	H_2O_2 accumulation dependent on NADPH-oxidase and phosphatidylinositol 3-phosphate
Oryza sativa [86]	100,200, 400mM $CdCl_2$	1 h	Regulation of MAP kinase activity by :non-enzymatic (OH•) and enzymatic ROS production (O2•− or H_2O_2) involving NADPH oxidase, CDPKs, PI3 kinase, and closing of the mitochondrial pore Regulation of NADPH oxidase and CDPKs activity by Ca^{2+}
Pisum sativum [87,88]	50µM $CdCl_2$	15days	Accumulation of O2•− and H_2O_2, Ca^{2+}-dependent decrease in NO levels, activation of peroxidases and NADPH oxidase
Pisum sativum [89]	100µM $CdCl_2$	48 h	Necrotic cell death associated with NO and H_2O_2 generation
Nicotiana tabacum (cell suspension) [90]	5mM $CdCl_2$	15 min	Oxidative burst mediated by Ca^{2+} , calmodulin and protein phosphorylation
Nicotiana tabacum (cell suspension) [91]	3mM $CdCl_2$	8 h	Three waves of oxidative stress: (1) transient, NADPH oxidase-dependent accumulation of H_2O_2 (2) increased production of O_2•− in mitochondria (3) fatty acid hydroperoxide accumulation concomitant with necrotic type of cell death Regulation of NADPH oxidase activity involving Ca^{2+}-mediated signaling and protein phosphorylation

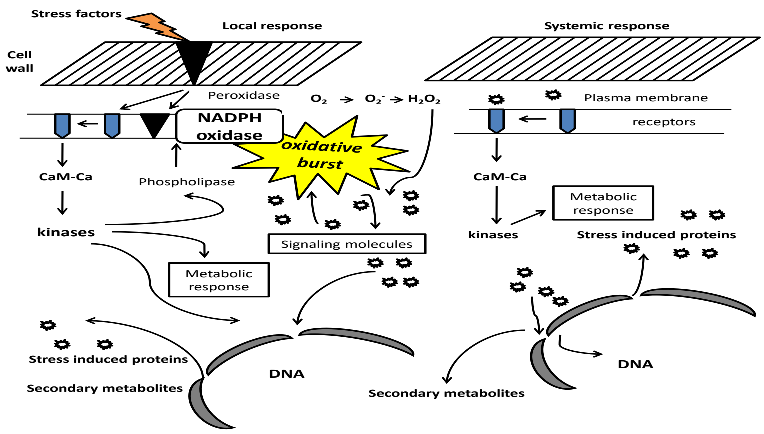

Fig-1: A general model for local and systemic stress signaling in plants

Table 1: Effect of Cd on stress proteins

Plant	Treatment	Effects	References
Zea mays	Cd exposure	Production of 70 kDa phosphoprotein (HSP)	[93]
Lycopersicon peruvianum	Pre-treatment with a short heat stress before Cd exposure	Preventing membrane damage. HSP17 (molecular weight 17 kDa) and HSP70 proteins were additionally found in the cytosol of heat-shocked cells.	[94]
Pisum sativum	Cd exposure	Pathogen-related proteins PrP4A and HSP71 were observed.	[88]
Triticum aestivum	50 µM $CdCl_2$ for 48 h	51-kDa soluble protein was found and protein was assigned as a Cd stress-related protein.	[95]
Populus tremula	Cd for a short term (14 days) or a more longer term (56 days) treatment	Stress related proteins, as HSPs, proteinases, and pathogenesis-related proteins, increased in abundance in leaves.	[96]
Oryza sativa	Cd exposure	Affected the synthesis of 36 proteins	[97]
Solanum lycopersicum	Low Cd concentration (10µM)	changes in 36 polypeptides	[98]
	Higher Cd level (100 µM)	changes in 41 polypeptides	[98]
Arabidopsis thaliana	10 µM Cd	Among 730 determined proteins 21 were up-regulated in response of Cd	[99]

CONCLUSION

Cadmium is a non- essential heavy metal which is phytotoxic and has negative impact on plants. It retards various physiological, morphological, biochemical and molecular activities of plant species. It is easily taken up by the roots of plants and causes severe damage to plant system. At higher concentration it may even cause death of the plant species. At low concentrations it can induce production of stress proteins and other secondary metabolites which indirectly help plants to resist against the oxidative damage caused by cadmium. This review highlights the effects of cadmium on various plant activities.

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